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NON-DESTRUCTIVE TESTING OF MATERIALS

The present invention relates to a method of localising damages or defects in objects or materials wherein a standing wave is generated within the object or material in order to detect damages or defects within an area of said object or said material by virtue of a reading obtained when measuring on the standing wave. The invention also relates to a localising arrangement that includes a signal source which is connected to a transmitter for generating a resonant sound wave within the object or within the material, and a receiver for receiving a measurement signal from the object or from the material connected to an apparatus for processing and analysing said signal.

It is known to use signal wave fields for detecting defects or damages in objects or materials. For example, according to US 4, 166, 393 a type of resonance excitation is used to this end, according to US 4, 823, 601 vibrations are created and measured with the aid of a laser, according to DE 38 42 061, a comparison is made between resonance frequencies in damaged and undamaged work pieces, US 5 408 305 describes a technique in which the mode configuration on the surface of the object is analysed in response to resonant oscillations, and DE 198 24 402 describes the processing of vibration data measured from work pieces and components. GB 1 184 333 describes a technique for detecting and localising construction defects, wherein a standing wave is generated in the tested construction. A defect located in the propagation path of the standing wave will be manifested by variations in the electric signal that feeds the acoustic signal source.

The object of the present invention is to provide an improved technique for detecting damages or defects in objects or materials and for enabling such damages or defects to be localised.

This object is achieved with a method and an arrangement of the kind defined in the introductory portion and having the respective characterising clauses of claim 1 and claim 4.

The technique proposed in accordance with the present invention may be

used conveniently in respect of extended structures, for instance thin metal sheeting, piping, etc.. A transmitter having a frequency and a diameter adapted to the geometry of the object and the properties of the material causes the object or the material to vibrate so as to generate a standing wave within the object between the vibration surface, e.g. the transmitter, and another surface in the object. When parameters are chosen correctly, the standing wave will be restricted essentially to a small area, e.g. between the transmitter and an opposing wall in the structure or the object. This standing wave is used to detect damages or defects in the object or material by use of Slow Dynamics, in other words through the agency of changes in the material properties of an object or a structure caused by an external influence, such as temperature changes, impact stresses, pressure changes or ultrasound influences, c.f. WO 02/079775. Because of the geometrical limitation of the standing wave, only damages or defects located within said area will result in significant readings in a measuring process.

The technique according to the present invention can be used beneficially with non-linear methods in which the standing wave constitutes the high frequency in, for instance, Nonlinear Wave Modulation Spectroscopy, where the standing wave is mixed with a low frequency signal that gives a sideband, or together with Slow Dynamics.

According to one beneficial embodiment of the inventive arrangement, the transmitter includes a concave transmitter element. This enables the standing wave to be concentrated so as to obtain an acoustic field that has an amplitude which is several times greater than the amplitude obtained with a flat transmitter element.

According to another beneficial embodiment of the inventive arrangement, the transmitter includes several transmitter elements. This also enables the standing wave to be concentrated, and also enables the acoustic field to be controlled in different directions by means of phase control.

According to further beneficial embodiments of the inventive arrangement, the transmitter includes a transmitting element that forms part of the object or

material to be tested. The transmitter element may also be provided with additional material of a given thickness, so that a standing wave can be generated with respect to the combined thickness of the transmitter element and the test object and therewith fulfil resonance demands. This will thus ensure that the resonance demands are fulfilled in the area influenced by the incoming wave, but not in the area outside the first mentioned area.

According to other beneficial embodiments of the inventive arrangement, the receiver includes a plurality of receiver elements, alternatively at least one piezo-electric sensor or a laser sensor. The presence of several receiver elements improves reception and also achieves better localisation of detected damages or defects. The use of separate sensors, such as piezo-sensors or laser sensors, enables the acoustic field to also be read on one side of the transmitter element or on other surfaces of the object, for instance on the opposite side of a metal sheet.

According to yet another beneficial embodiment of the inventive arrangement, the transmitter and the receiver can be moved across the object or material to be tested, and the signal source includes an automatic frequency control facility with which the frequency can be changed so as to retain resonance as the transmitter and the receiver are moved. For instance, if a transmitter and a receiver are moved over the surface of an object or of a material, it is possible for the thickness of the object or the material to change and therewith change the resonance frequency of the chosen mode. It is then necessary to change the transmitter frequency correspondingly.

In order to limit the standing wave to a small area, it is essential that the radiation angle of the signal is as small as possible, meaning that the spread of energy will be small. According to another advantageous embodiment of the arrangement according to the invention the radius of the transmitter and the frequency of signal source are therefore adapted to give the transmitter output signal a small beam angle.

A contactless technique is desirable, or necessary, in the case of many applications of acoustic non destructive testing methods, such as linear and non-

linear ultrasound methods for instance. According to further beneficial embodiments of the inventive arrangement, the receiver therefore includes at least one laser sensor or at least one microphone for contactless reception of the measurement signal from the object or the material. The contactless transfer of the low frequency part of the signal can, for instance, be achieved with the aid of an air pistol although the transfer of the high frequency part of said signal is more difficult to achieve, due to the large impedance difference between transmitter and air and between air and transmitter. According to still another beneficial embodiment of the inventive arrangement, the transmitter is, for this reason, adapted to the object or to the material for the contactless transfer of sound energy thereto, so as to create an open resonator between transmitter and object or material. Such a resonator recovers the energy in the oscillations and collects said energy by utilising existing modes in the object or the material. The air present between the object to which the acoustic energy shall be transferred and the transmitter thus also have modes. The use of standing waves in air also results in a multiple increase in the wave amplitude on the passive side of the resonator. The amount of energy transferred to the object will be many times the energy transferred when the object constitutes the passive side of the resonator than when resonance is not used. This technique can be used both in respect of linear and non-linear methods.

According to another beneficial embodiment of the inventive arrangement, the transmitter includes a parametric transmitter with disappearing sound. This further enhances the possibility of exciting solely a given area in the object or in the material; c.f. Swedish patent application 0104201-9.

The invention will now be described in more detail with reference to exemplifying embodiments thereof and also with reference to the accompanying drawings, in which fig. 1 illustrates a first embodiment of an arrangement according to the invention, fig. 2 illustrates the effect achieved with transmitter elements of mutually different design; fig. 3 illustrates the results of experiments carried out on a Plexiglas sheet; fig. 4 illustrates examples of the variation in beam angle as a function of frequency and transmitter radius; fig. 5 illustrates application of the invention in respect of an object of particular structure; fig. 6 illustrates

pressure distribution in respect of different types of resonators; fig. 7 illustrates examples for obtaining a limited wave field; fig. 8 illustrates a second embodiment of the an arrangement according to the invention; fig. 9 shows an example of the relative positions of the frequencies in respect of conceptual amplitudes, when using the disappearing sound technique; fig. 10 illustrates further conditions in respect of so-called disappearing sound; and fig. 11 is a damage position indicating curve obtained by excitation of successively different modes of oscillation in the tested object or the tested material.

Shown in fig. 1 is a first embodiment of inventive an arrangement that includes a signal source in the form of a signal generator 2 which functions to generate a signal that is sent to the transmitter 4. The transmitter 4 creates on the object 6 vibrations whose frequency and diameter are adapted to the geometry of the object and to the properties of the material, so as to form a standing wave within the object, between the vibration surface, i.e. the transmitter 4, and an opposing surface 8 of the object 6. In the case of the fig. 1 embodiment, transmitter and receiver are arranged in one and the same unit 4 and the receiver element is connected to a signal-detecting oscilloscope 10.

When parameters are chosen correctly, the standing wave, illustrated with curved wave parts 11 within the object 6 in fig. 1, will be limited essentially to a small area, namely the area between the transmitter 4 and the opposing wall 8 in the object. As a result of the geometrical limitation of the standing wave, only damage or defects, such as the crack 12, will give readings of any significance in the measuring process.

The transmitter element and the receiver element are conveniently movable over the surface of the object 6. In this regard, the signal generator 2 is beneficially equipped with automatic frequency control so as to lie constantly in resonance, even when the conditions are changed as the transmitter element and the receiver element 4 are moved across the surface, for instance as a result of a change in the thickness of the object so as to change the resonance frequency for the mode chosen.

transmitter with disappearing sound to excite a given area by means of a frequency difference, for the purpose of localising cracks, for example.

The designation frequency difference is used below as an example of the frequency of interest that is first created and then extinguished by higher frequencies. This need not be a frequency difference, but may be another frequency concerning other sorts of modulations, for instance frequency modulations or amplitude modulations of the signal. Notwithstanding, we designate the locally occurring frequency below as the " frequency difference", since the example described hereinafter with reference to fig. 9 utilises precisely the frequency difference, c.f. Swedish patent publication 01042201-9.

A first non-linearity that creates the frequency difference resides in the inherent non-linearity of the material, which is assumed to be relatively low. This means that the signals that shall create f2 and f2 + Δ and extinguish f1 and f1 + Δ, the frequency difference, must be strong.

The second non-linearity of significance in this context resides in the non-linearity that indicates the presence of cracks. Because cracks are pronouncedly non-linear, this non-linearity is often several magnitudes greater than the natural non-linearity of the material, wherewith the strength of the signals, Δ and f0, that shall form sidebands in the presence of cracks etc. need not be so great.

For the detection of cracks, there are sent signals of high amplitude and two high frequencies, f2 and f2 + Δ, which co-act non-linearly due to the inherent non-linearity of the medium and give parametrically a frequency difference Δ. The amplitude of this frequency is much smaller than the amplitude of the signals having the frequencies f2 and f2 + Δ.

There is moreover sent a signal having the frequency f0, which is possibly in resonance. This frequency corresponds to the high resonance frequency, whereas the low frequency signal corresponds to the frequency Δ in this case. It can therefore create a sideband around the frequency f0, i.e. a sideband of f0 + Δ and of f0 - Δ around f0.

The frequency Δ is then extinguished by two further signals of high amplitude and high frequencies f1 and f1 + Δ which form antisound to the sound formed by the signals of frequencies f2 and f2 + Δ.

This enables a sideband to be created within the region in which the frequency difference Δ is present. We can thus localise the damage or defect to this region. Of course, it can be read outside the region itself.

Fig. 9 is a schematic illustration of the relative positions of the frequencies having conceptual amplitudes, as given in the aforedescribed exemplifying embodiment.

Parametric sound will automatically have a small beam angle and is thus localised in a purely radial direction. Moreover, longitudinal propagation of the sound can be limited, as illustrated in fig. 10. There is shown at the top of the figure a one-dimensional image of the amplitude of the aforesaid frequency difference of the disappearing sound as a function of the distance. The frequency is then created and extinguished.

The lower part of fig. 10 shows a transmitter 24 for transmitting disappearing sound in an object 26, wherewith the approximate region of the disappearing sound is illustrated conceptually by the grey-coloured area 28 in the figure.

The direction of the beam can be controlled with the aid of a phase controlled transmitter that includes several transmitter elements and the location of the frequency difference can be controlled by different frequency selection. This embodiment thus enables several different areas to be tested and thus enables different defective or damaged areas to be tested and localised without moving the transmitter.

It will also be noted that different modes give different nodes for the standing wave and the resultant non-linear response will depend on the extent to which the standing wave is influenced by the damage or defect in the object, and

vice versa. The use of several different modes that investigate different parts of the object enables the non-linear responses to be weighted so as to provide a picture of where the damage or defect can be found. Those methods known hitherto give a degree of ambiguity due to the fact that the modes and the functions are symmetrical, or are ambiguous for some other reason, see Didenkulov et al, "Modulation modal method for crack location", Proceedings of Tenth international Congress on Sound and Vibration, 7-10 July 2003, Stockholm, and Didenkulov et al, "Nonlinear acoustic technique of crack location" in W. Lauterborn and T. Kurz ed. "Nonlinear acoustic at the turn of the Millenium", Melville, New York, 2000, pp. 329-332.

This ambiguity disappears when a part of the tested unit or the tested medium is allowed to consist of a material which is known to contain no defects or damages. This material may, for instance, consist of the air used in a contactless apparatus, such as described above. Alternatively, a material part may be used to give a better localised wave field, as described above.

Fig. 11 illustrates examples of different oscillation modes of an object that has a defect or damage located at position X2. Fig. 11a illustrates a first mode – non-linear response ε_1, fig. 11b illustrates a second mode – non-linear response ε_2, fig. 11c illustrates a third mode – non-linear response ε_3, and fig. 11d illustrates a fourth mode – non-linear response ε_4.

Different non-linear responses ε_N can be obtained, by exciting one mode at a time. The mode forms can be weighted with these responses in various ways, which are well known to the person skilled in the art and will not therefore be described in more detail here, so as to obtain a damage position indicating curve such as that shown in fig. 11e. Fig. 11e thus shows a damage position indicating curve which is obtained from modes weighted with non-linear responses, said curve having two maxima at X1 and X2.

If, in the case illustrated in fig. 11, an object was damage free from O to L it would have been impossible to determine whether the damage was located at position X1 or at position X2. When a damage free medium is positioned in front of

the object being tested and constitutes part of the tested unit consisting of said object and a damage free medium it will be known that the damage exists at X2, said damage free medium being air in the fig. 11 illustration, although may also consist of a solid or a liquid medium.

It will be noted that the image is schematic. In the case of different materials, the wave form will either be extended or compressed in the X-direction of the different media, due to the fact that the wave velocities differ. In the case of the example shown in fig. 11, the sound velocity is the same in both object and air. This has no principle significance, however, but is solely due to length scaling.